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PRELIMINARY ASSESSMENT OF A BIRD RIVER CHROMITE DEPOSIT

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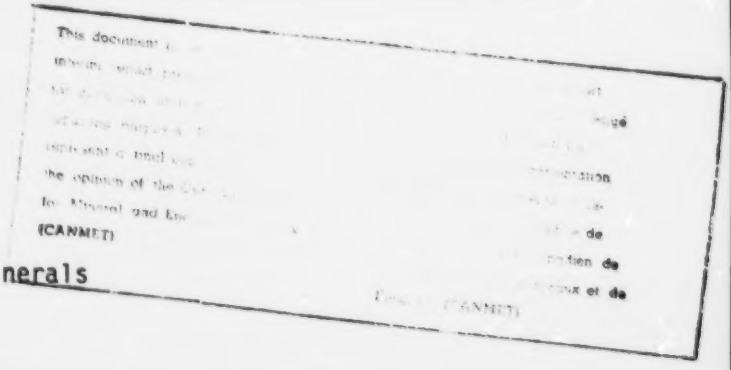

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MICROMEDIA

PRELIMINARY ASSESSMENT OF A BIRD RIVER CHROMITE DEPOSIT

by

P.R.A. Andrews* & D.P. O'Shaughnessy**

ABSTRACT

In the manufacture of stainless steel, the chromium content is provided in both a primary form as chromium ferroalloys and in a secondary form as stainless-steel scrap. The chromite of the Bird River deposits in south-eastern Manitoba is low grade and unsuitable for use in the manufacture of any of the commonly traded grades of ferrochromium alloys. Since the end product is essentially stainless steel, the ferroalloys are only intermediate metallurgical products containing chromium in various standard forms. It is therefore reasonable to consider the manufacture of stainless steel directly from low-grade chromite, and in this way any intermediate chromium products would not need to find a niche in the ferroalloys markets.

An economic assessment of the Chrome deposit which comprises a part of the Bird River chromite deposits was conducted by Hatch Associates Ltd. of Toronto, as part of the Canada-Manitoba Mineral Development Agreement. The study included a geological assessment of the Chrome deposit, development of both a mining plan and a gravity concentration circuit as well as processes to smelt the chromite to ferrochromium and convert this product directly to stainless steel. In addition, a preliminary review of North American consumption patterns of various chromium products was completed.

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The study concluded that a facility producing 180,000 tonnes per year of semi-finished stainless steel would be economically viable, and also that it would be more profitable to manufacture 300 series (chrome-nickel) rather than 400 series (straight chrome) grades. This annual quantity of stainless slab would necessitate mining 3,500 tonnes per day of ore and the smelter would process 174,000 tonnes per year of 30 percent Cr_2O_3 concentrates with a 0.85:1 chrome to iron ratio.

Keywords: Chromite, Economic Assessment, Geology, Mining, Mineral Beneficiation, Smelting, Stainless Steel, Markets.

ÉVALUATION PRÉLIMINAIRE D'UN GISEMENT DE CHROMITE DE BIRD RIVER

par

P.R.A. Andrews et D.P. O'Shaughnessy

RÉSUMÉ

Dans la fabrication d'acier inoxydable, la teneur en chrome se présente sous forme primaire dans des ferro-alliages de chrome et sous forme secondaire dans des résidus d'acier inoxydable. Le chromite des gisements de Bird River dans le sud-est du Manitoba est de faible qualité et impropre à la fabrication de toutes qualités commerciales courantes d'alliages de ferro-chrome. Comme le produit final est essentiellement de l'acier inoxydable, les ferro-alliages ne sont que des produits métallurgiques intermédiaires contenant du chrome sous diverses formes standard. Il est par conséquent fondé d'envisager la fabrication d'acier inoxydable directement à partir de chromite de faible qualité. De cette façon, il ne serait pas nécessaire de trouver une place sur les marchés des ferro-alliages pour les produits de chrome intermédiaires.

Une évaluation économique du gisement de chrome qui inclut une partie des gisements de chromite de Bird River a été réalisée par la Hatch Associates Ltd, de Toronto, dans le cadre de l'entente Canada-Manitoba de mise en valeur minérale. Il s'agissait dans cette étude d'éffectuer une évaluation géologique du gisement de chrome, de mettre au point un plan d'exploitation et un circuit de traitement gravimétrique ainsi que des procedés de fusion de la chromite en ferro-chrome et de convertir directement ce produit en acier inoxydable. De plus, une analyse préliminaire de modes de consommation en Amérique du Nord de divers produits du chrome a été réalisée.

Selon les conclusions de l'étude, une installation produisant 180,000 tonnes par années d'acier inoxydable semi-fini serait économiquement viable et il serait en outre plus avantageux de fabriquer des produits de série 300 (chrome-nickel) que ceux de série 400 (chrome non allié). Pour produire cette quantité annelle de brame inoxydable, il faudrait extraire 3500 tonnes de minerai par jour et traiter en fonderie 174000 tonnes par année de concentrés Cr_2O_3 30 pour cent dans un rapport chrome-fer de 0,85/1.7

INTRODUCTION

Most low grade chromium resources are periodically reviewed by their owners and other potential investors in order to determine if a blend of new technologies and changing markets can provide the opportunity for commercial exploitation. In the late 1950s, for example, the American Chrome Company developed a process to manufacture a 50 to 55 percent chromium ferroalloy from Montana chromites[1]. In spite of being a technical success, this "charge chrome" could not be competitively priced and its low chromium content was found to be unacceptable to the steelmakers at that time. Ten years later this same grade of ferrochromium manufactured from Transvaal chromites found its niche in the market not only because the price was competitive, but also because of a new technology, the Argon Oxygen Decarburization (AOD) process.

During the 1970s and early 1980s, the locations of major ferrochromium smelting activity have moved away from North America, Western Europe and Japan such that western steelmills have now become almost totally dependent on off-shore sources (imported) for their chromium ferroalloys[2]. These moves have had the effect of bringing to the forefront security of supply issues since chromium is commonly accepted as being a critical material.

The Bird River chromite occurrence in south-eastern Manitoba is a good example of a low-grade deposit that has defied commercialization because of its geology, location and grade. Several studies[3] have been carried out since its discovery in 1940 to determine the possibility of producing a standard grade of concentrate or even chromium ferroalloys, but the products could not compete in the marketplace. A new approach to the commercialization of the Bird River deposits was developed in the early 1980s by engineers at Hatch Associates[4] with a process in which the iron content of the chromites could be sold as well as the chromium. The concept incorporated mostly standard equipment but the end-product was stainless steel, not an intermediate metallurgical product whose only value would be its chromium content[5].

As part of the Canada-Manitoba Mineral Development Agreement, Hatch Associates Ltd. of Toronto was commissioned in 1986 by Energy, Mines and

Resources, Canada to prepare a pre-feasibility evaluation for the possible future economic development of a Bird River chromite deposit using previously developed flowsheets as a broad guideline[6]. This work has been identified as Phase three of a four-part program. Phase one entailed the mining and transportation of a 70 tonne sample of chromite ore from the Chrome deposit. Phase two, laboratory and pilot-plant beneficiation of the 70 tonne sample, was undertaken by Lakefield Research, Lakefield, Ontario[7] and this work provided the background data for Phase three.

SCOPE OF STUDY

This economic viability study of a Bird River chromite ore for use in the manufacture of a chromium-bearing product has been based on an assessment of each of the following:

1. Chromium consumption patterns in the US industry.
2. Geology of the deposit.
3. A feasible mining method.
4. Concentrator flowsheet.
5. Production of stainless steel.

General Considerations

While economic viability is based on results which apply specifically to the Chrome deposit, it has been assumed with a reasonable degree of confidence, that the same conclusions will apply to the other chromite deposits comprising the Bird River ore body.

The mining information and cost estimates are based largely on current Canadian operating practices and limited geological data. The cost estimates were developed from first principles and verified by review of current open-pit operations in Northern Ontario. Mine site access, infrastructure development and cost estimating for the required mining rate are therefore first order estimates. Concentrator, smelter and stainless steel production cost data has been developed using both first principles and an evaluation of current operations.

THE NORTH AMERICAN MARKET FOR CHROMIUM

Chromium Products

In North America, 70 percent of primary chromium is consumed as ferroalloys in the production of stainless steels, 25 percent as chromite in the production of chrome chemicals and 5 percent as chromite in the production of refractories. Up until the late 1970s, chromium ferroalloys were produced in North America from imported chromite, but most chromium used in stainless steel manufacture is now imported as ferroalloys. Chromite used in the production of chrome chemicals and refractories is all imported material.

A major source of primary chromium to the steel industry is "charge chrome" which contains 50 to 55 percent chromium and is typically produced from chromite concentrates analysing 45 percent Cr_2O_3 with a Cr to Fe ratio of 1.6:1. Since 70 percent of all primary chromium consumption is as ferroalloys, and 80 percent of all chromium ferroalloys are consumed in the production of stainless steel, the stainless steel sector therefore accounts for 55 percent of the total North American primary chromium requirement. This amount may be further divided into 47 percent as high-carbon ferrochromium/charge chrome and 8 percent as other chromium ferroalloys such as low-carbon ferrochromium and ferrochromium-silicon.

Stainless steels are designated as chromium-nickel grades (the 200/300 series steels) which account for 75 percent of total stainless production, and straight-chrome grades (the 400 series steels) which account for the remaining 25 percent. Sheet and strip-steel products of both series of grades amount to 60 percent of the total stainless market with the balance being plate, bar, rod and wire. Presently, 20 percent of the total US stainless market is being supplied by imports, primarily from Europe and Japan; Canadian/US trade in stainless steel is relatively small and subject to controls.

United States Chromium Imports

North America imports 95 percent of its ferrochromium requirements; stainless and heat resisting steels produced in the United States from these imports during 1986 approximated 1,500,000 tonnes, requiring about 140,000 tonnes of primary chromium (see Table 1). This latter quantity equates to

approximately 270,000 tonnes of ferrochromium. South Africa supplied 61 percent of the high-carbon ferrochromium imports, and 41 percent of the low-carbon ferrochromium imports consumed in the US in 1986. Other significant import sources were Turkey, Zimbabwe, Finland and Brazil.

Imports of stainless-steel products as a percentage of domestic production have risen from 10.9 percent in 1983 to 17.5 percent in 1986 (see Table 2), while the US industry has been operating close to full capacity. The majority of the stainless-steel imports are in the finished condition; imports of hot-rolled sheet for cold finishing have been fairly consistent during this period, and there has been a small but increasing quantity of semi-finished steel being imported in the form of ingots, blooms, slabs and billets.

United States Stainless Steel Production

The major producers of stainless steel sheet and strip in the United States are all located in the area around Pittsburgh, Pennsylvania. Stainless-steel production consists of two distinct and separate operations. The melting and alloying of the steel to produce a specified product in the form of an ingot, bloom, slab or billet which is known as semi-finished steel, and the reheating and forming of this steel into a shape suitable for use by the manufacturing industries. It has been observed from published data that the finishing capacity of some of the major integrated stainless operations is in excess of the melting or steel producing capacity.

There are fourteen stainless-steel producers in North America with approximately 2.1 million tonnes per year of melting capacity; the major producers are reported in Table 3 and the stainless-steel sector is presently operating at close to rated melting capacity.

GEOLOGICAL ASSESSMENT

The principal geological considerations, which have an impact on the technical and economic viability of a commercial development of the Chrome deposit, are based on information from the Manitoba Department of Energy and Mines open-file reports and other sources (8-12).

Geological Setting

The Bird River sill is a layered ultramafic to mafic intrusive complex averaging about 600 m thick inferred from surface outcrop. This sill forms an eastward plunging anticline with both limbs dipping steeply at 60 to 90 degrees. The south and north limbs are respectively 32 and 24 km in length. Continuity, however, is interrupted by faulting and younger granite intrusives, so that the total length of the outcrop and sub-outcrop beneath overburden and water may not exceed 30 km.

The 70 tonne bulk sample, used in the Phase two program of beneficiation testwork at Lakefield Research, was taken from the southern limb of the Chrome deposit.

The Chromitiferous Zone

The Chromitiferous zone is about 60 m thick inferred from surface outcrop and occurs near the top of the ultramafic portion of the Bird River sill as shown in Fig. 1. Chromite occurs as numerous narrow chromitite layers, disseminated layers and scattered grains within intercalations of serpentinized picrite, peridotite and dunite. The highest concentrations of chromite occur within two zones that are designated Upper Main Zone and Lower Main Zone. The Upper Main Zone (average width 2.59 m) consists of three dense closely-spaced chromitite seams. The Lower Main Zone has most of its chromite concentrated in a dense seam (average width 0.64 m) at the top of the zone.

The 70 tonne bulk sample represented a cross-section from the uppermost seam in the Upper Main Zone up to and including the upper seam in the Lower Main Zone. This cross-section appeared to have the best potential for a relatively wide in-situ ore zone. For convenience, it is referred to as the "Main Zone".

A pit outline may encompass narrow chromite seams and disseminations outside the "Main Zone" which include a thin band known to contain low levels of platinum group minerals (PGMs), about 30 m from the foot wall. There is, however, no available evidence to suggest that any of this material would make a significant contribution to economic viability.

The "Main Zone" is approximately 17 m wide which for economic purposes, can be conveniently divided into the relatively rich Upper Main Zone with an average width of 2.59 m; the rich Lower Main Zone with a 0.64 m average width and the low grade middle zone which averages 13.8 m. The middle zone

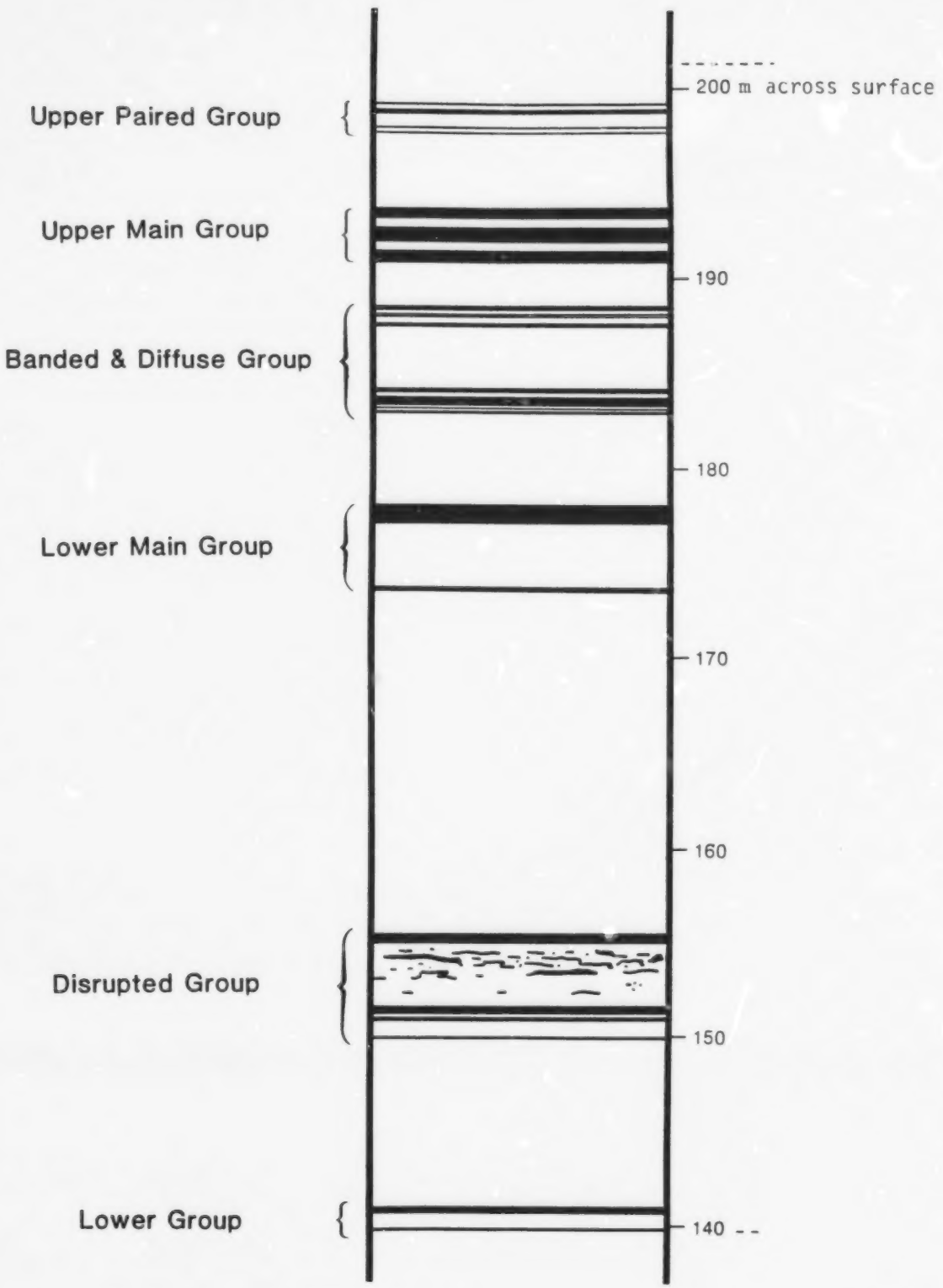

Fig. 1 - Chromitiferous zone stratigraphy.

(After Bannatyne, B.B. et al - Dept. of Energy & Mines, Man.
Scoates, J.S. et al - Geol. Survey of Canada, Ottawa).

consists of the weakly-mineralized banded and diffuse zone which is flanked on both sides by virtually barren rock. An estimate of the grade and tonnage distribution in the "Main Zone" is presented in Table 4.

MINE DESIGN

General Considerations

Based on known geological considerations it is believed that bulk open-pit methods would best suit the mining of Bird River chromite ore. A typical cross-section of the Chrome deposit with a planned open-pit slope of 55 degrees at depths of 50 m and 100 m is shown in Fig. 2. Three or more pit areas would be worked simultaneously, so that pit deepening would be limited to a selected bench height of 10 m in order to ensure grade control.

There is a significant amount of transverse faulting with major blocks having strikes of 30 m to 500 m; this effect will influence pit design when attempting to control dilution. An order of magnitude dilution factor of 10 percent is considered appropriate, but since loss of ground by faulting is anticipated, the diluted tonnage has been equalized to the loss of ground factor.

Mine Reserves

Mined tonnage and pit life are based on a concentrator capacity of 1,225,000 tonnes per year and are tabulated as follows:

Pit Depth (Meters)	Ore (tonnes)	Waste (tonnes)	Ore Life (years)	Stripping Ratio
50	6,523,750	24,890,000	5.33	4.82
100	13,047,500	76,806,000	10.65	6.89

The present ore potential is considered to be amenable to open-pit mining to a depth of either 50 or 100 m, based on interpretation of data. The estimated reserves to a 100 m depth are in excess of 13 million tonnes for the Chrome deposit alone and there is the potential of ore at greater depths.

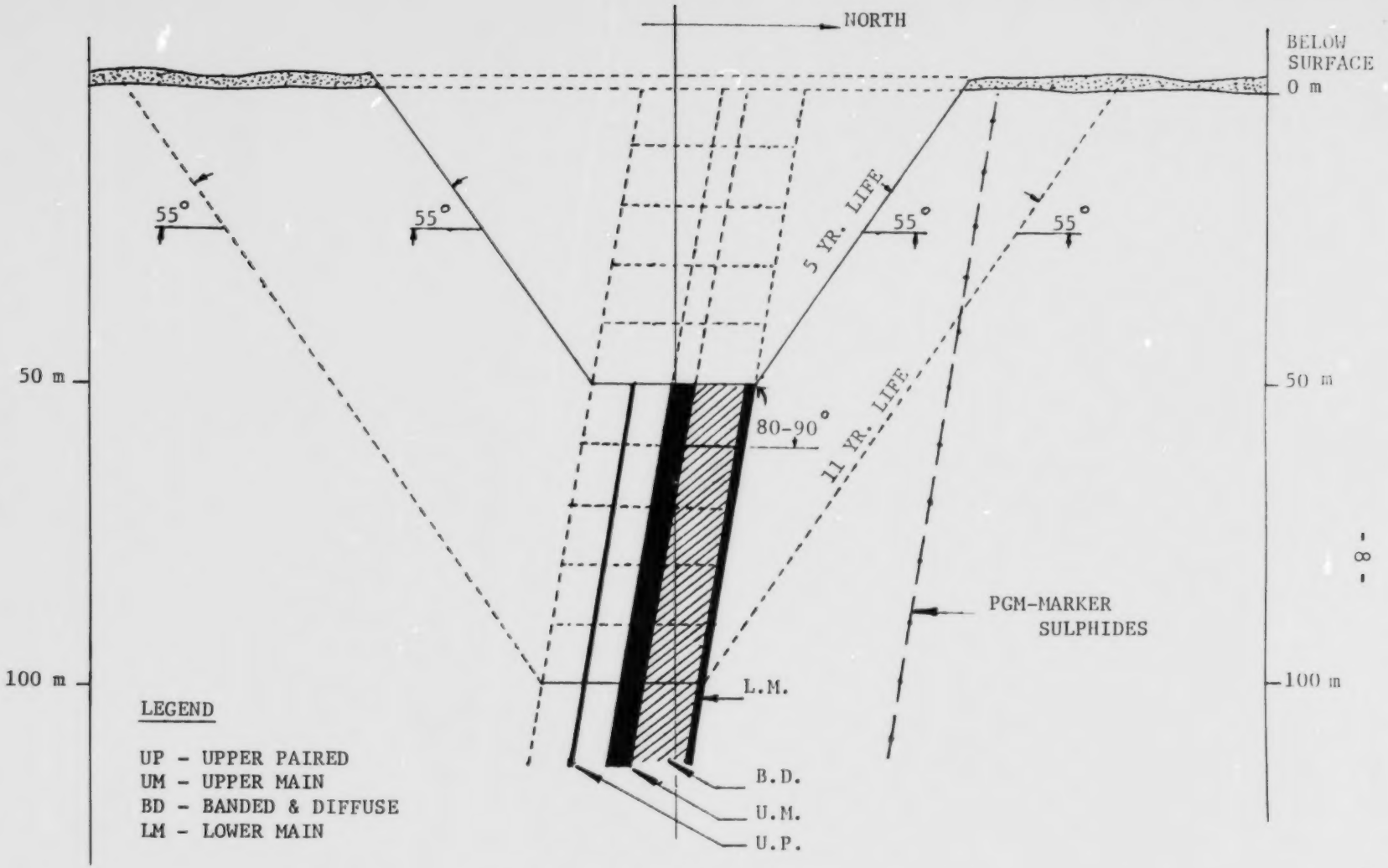

Fig. 2. Open pit(s) Ideal cross section looking west

Preliminary geological considerations from the available data have resulted in the conclusion that selective underground mining of the relatively narrow and high-grade chromitite seams contained in the sampled "Main Zone" would be extremely expensive and difficult, due primarily to the existence of weak ground. The immediate serpentine and olivine associated with the high-grade chromitite veins are weak host rocks, and there are a number of transverse faults. Economic viability for open pit and underground mining can, however, be enhanced by considerations of waste ore sorting at the mine site. The procurement, however,of more detailed geological sampling and geotechnical structural data are essential for detailed cost and mine planning.

CONCENTRATOR FLOWSHEET

Flowsheet Development

In May 1986, the 70 tonne sample of Bird River chromite ore from the Chrome deposit was received at Lakefield Research. Subsequent beneficiation evaluation involved both laboratory and pilot scale testwork. In the laboratory phase, flowsheet development included grinding, gravity separation and flotation. The gravity concentrates were upgraded by magnetic separation and the flotation concentrates by gravity concentration. Pre-concentration by electronic ore sorting, magnetic separation and heavy-media separation also was examined.

The optimum flowsheet was applied in the pilot-plant to the ore as received, and to ore that had been pre-concentrated by electronic ore sorting and magnetic separation. Ore pre-concentrated by heavy-media separation was treated on a laboratory scale but generally following the pilot-plant flowsheet.

Processing the ore as received resulted in a 77 percent recovery of chromite in a concentrate analysing 30 percent Cr_2O_3, and processing ore pre-concentrated by electronic ore sorting resulted in a 64 percent recovery of chromite in a concentrate analysing 30.5 percent Cr_2O_3. Processing ore pre-concentrated by heavy-media separation resulted in a 67 percent recovery of chromite in a concentrate analysing 30.0 percent Cr_2O_3(7).

Concentrator Design

A review of the various processing techniques that were tested indicated the preferred treatment would be pre-concentration by heavy-media separation using a Tri-flo TFS 150 separator. The heavy media accept product, however, was not further treated on a pilot-plant scale, but various flowsheets were tested on a laboratory scale using a composite sample of the accept products. The resulting recommendation was that subsequent beneficiation should only be by gravity separation. Laboratory flotation and magnetic concentration of gravity separation products did not demonstrate any economic improvements to the overall flowsheet. The final flowsheet therefore, as shown in Fig. 3, incorporates the assumption that the final concentrate can be achieved by regrinding middlings from both the rougher and cleaner gravity separation circuits.

PRODUCTION OF STAINLESS STEEL

Process Description

The feed material to the smelting operation is a chromite concentrate which reports from the adjacent mine concentrator in slurry form. The slurry is dewatered to eight percent moisture, mixed with coke fines and bentonite and then pelletized. The green pellets are sintered, cooled and transported to covered storage. The batching plant mixes the pellets with reductants such as coke and possibly coal, as well as fluxes which may include quartz, dolomite and limestone. The batched material is smelted in a submerged-arc furnace of standard design employing Soderberg (self-baking) electrodes. The "molten ferrochromium alloy" analyzing 40 percent chromium is transferred to one of two induction furnaces where the chromium is diluted by the addition of mild steel scrap. The resulting "transfer metal" is charged to an Argon-Oxygen Decarburization (AOD) vessel where the carbon is blown down to a low level. The "blown metal" is molten stainless steel which is transferred to the continuous caster for the production of slabs. Analyses of the products in the various stages of processing are reported in Table 5.

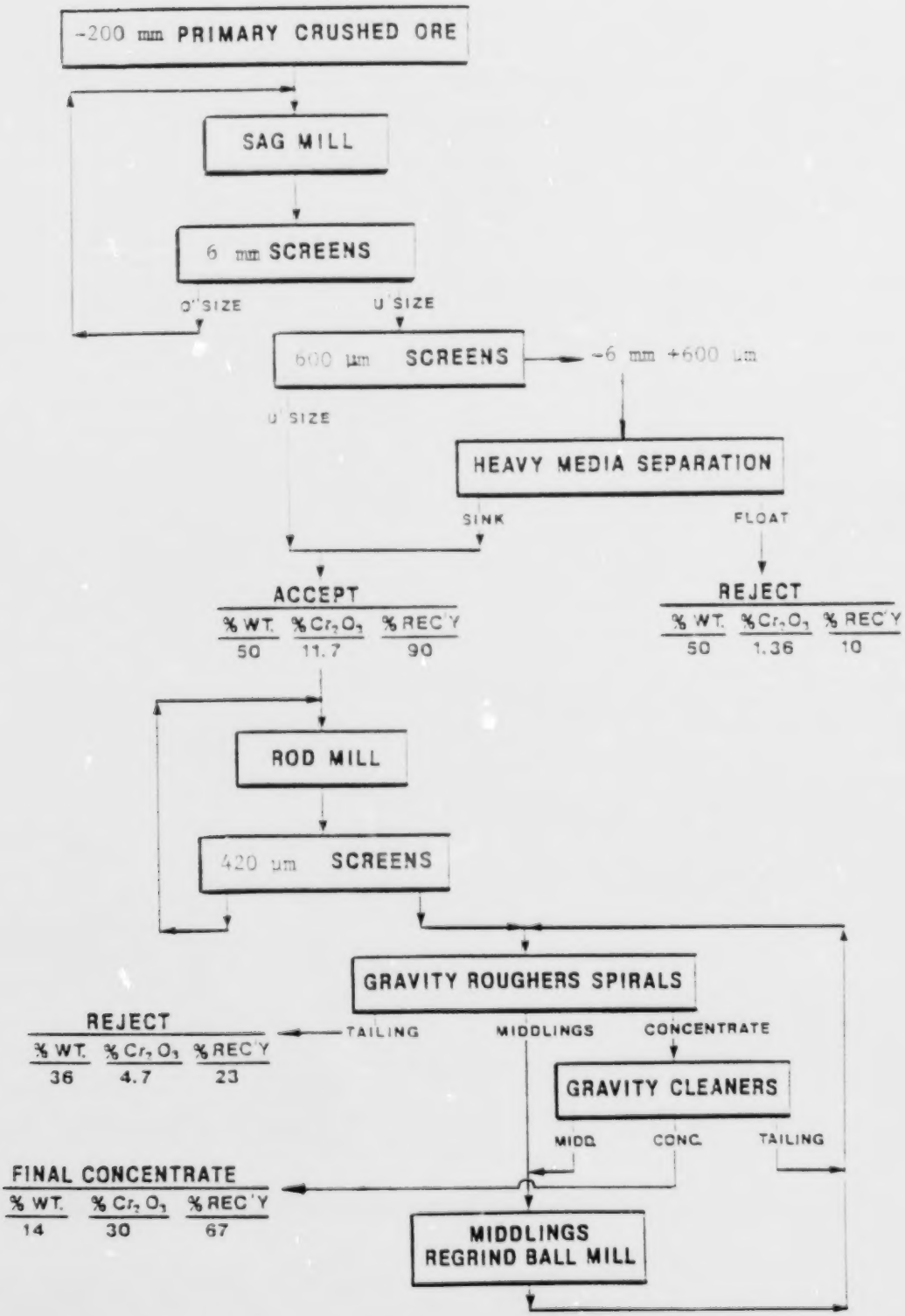

Fig. 3. Concentrator flowsheet.

Furnace gas contains approximately 85 percent carbon monoxide and is considered to be a medium-value calorific gas. The furnace gas is scrubbed to remove dust and fume. The gas pressure is then raised as the gas is transferred to a gas holder. This gas will be sufficient to supply all of the energy needed for sintering, ladle drying and several sundry demands within the plant.

Activity Operating Costs

Comparison of Bird River chromite concentrates with commercially available low chrome to iron ratio concentrates indicates that the Bird River material is too low grade and high priced to be able to compete as a marketable concentrate.

In order to minimize the effect of overhead costs to the overall operation while limiting steelplant output to approximately ten percent of United States stainless steelmaking capacity, an annual production rate of approximately 180,000 tonnes of stainless-steel slab was selected. At that time,(6) 75 percent of this capacity was considered to be 300 series (chrome-nickel grades) and 25 percent as 400 series (straight-chrome grades), since this ratio generally reflects the market balance for these grades of stainless steel.

The process calculations have been developed on the basis of 136,000 tonnes per year of 300 series and 45,000 tonnes per year of 400 series stainless steels. The average steel slab analysis for estimating purposes would therefore be approximately 16.5 percent chromium and 6.0 percent nickel. Even after allowing for the cost of transportation of the slab from Manitoba to Pittsburgh, it has been shown that the cost of slab produced directly from Bird River chromite could be approximately 25 percent lower than slab produced by the scrap-based stainless producers.

It may be expected that process optimization will result in further cost savings which can serve only to increase the cost advantage of stainless slab from Manitoba compared with that currently produced in the United States. While cost savings may be gained by implementing alternative technologies it may be determined that the major operating cost component is the nickel which has been included in the steelmaking costs (see Table 6).

Alternative sources of nickel may be employed directly in the smelting process rather than utilizing electrolytic nickel in order to lower steelmaking costs.

DISCUSSION

The concentrates produced from Bird River chromite must be converted into a saleable product which is competitive in the North American market. The alternative consideration that substantial chromite reserves be considered only as a strategic source of chromium available in case of a possible supply interruption to North American steel mills invites the acceptance of a high cost operation. While platinum group minerals (PGMs) have been identified as occurring in the Chrome deposit, the levels identified so far indicate that PGMs should not be given any further consideration. Should PGMs, which are traditionally associated with chromites, be found at a later date in economically recoverable amounts, the scale of the overall operation could be reduced and/or the overall economics substantially improved.

Due to the geotechnical aspects of the deposit, it is apparent that the mining and concentrating costs will not result in a competitively priced chromite product. The narrowness of the "ore" zone combined with the 80 to 90 degree attitude of the deposit results in a high waste to ore ratio in the open-pit operation. This in turn restricts the depth of operations if the costs are to be contained within reasonable limits. As a result, the operating life of the Chrome deposit is restricted to a maximum of eleven years. However, since there are seven other deposits comprising the Bird River complex, the operating life of the entire chromite ore body would be considerably longer.

Chromium ferroalloys are sold on the basis of the contained chromium, and therefore lower grade alloys are at a competitive disadvantage relative to standard grade material because of the higher smelting costs and freight charges. The high carbon ferrochromium market presently trades in three grades which contain 50 to 55 percent, 56 to 64 percent and greater than 64 percent chromium. An alloy containing only 40 percent chromium (the indicated quality Bird River chromite) would not be marketable unless it was offered at a discount to the 50 to 55 percent grade material.

Therefore, a steel mill integrated directly with the ferrochromium smelter is essential in order to achieve economic viability. The potential therefore exists for Manitoba to become a producer of semi-finished steel in the form of stainless-steel slab and, should the market indicate, further processing to hot band for delivery to finishing operations in the United States or overseas, which already have established markets for their products.

CONCLUSIONS

A preliminary assessment of the North American market has indicated that production of 180,000 tonnes per year of stainless-steel slab (semi-finished steel) would be economically viable. This operation would require the production of approximately 170,000 tonnes per year of 30 percent Cr_2O_3 concentrates, and a mining operation capable of 3,500 tonnes per day of ore. Concentrator design has been based on heavy-media separation followed by gravity concentration circuits. The proposed mining method is open-pit, operating sequentially along the strike length. The primary pit depth will be 50 m and the pit depth can be extended to 100 m with a pit slope of 55 degrees. From the same molten ferrochromium alloy, the production of 300 series stainless steels has been shown to be more profitable than 400 series steels.

RECOMMENDATIONS

As a result of the favorable outcome of the pre-feasibility study, it has been recommended that consideration should be given to completing a full-scale engineering study for the feasibility of a mine-concentrator-smelter-steelplant complex. However, the logical sequence of events that would preceed the feasibility study are as follows:

1. Identify customers, tonnages and grades.
2. Refine the process in order to further minimize operating costs.
3. Initiate additional exploration work on the Chrome deposit and eventually complete a drilling and core-sampling program.
4. Operate a pilot plant program on-site in order to optimize concentrator operations.

5. Complete pilot tests to confirm the technical aspects of the smelting and steel refining operations.

Items 1 and 2 above will be carried out during 1988 as part of the on-going developments funded under the Canada-Manitoba Mineral Development Agreement.

ACKNOWLEDGEMENTS

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Table 1

United States steel industry data

	Total raw steel production (tonnes)	Stainless & heat resisting steel production (tonnes)	Primary chromium units consumed per tonne S&HR steel prod. (kg)	Total primary chromium consumed in the S&HR steel sector (tonnes)
1980	107,500,000	1,540,000	103	159,000
1981	109,700,000	1,580,000	101	159,000
1982	67,700,000	1,120,000	90	101,000
1983	76,800,000	1,590,000	105	167,000
1984	84,000,000	1,610,000	96	154,000
1985	79,300,000	1,530,000	96	146,000
1986	74,100,000	1,530,000	99	152,000
1987*	80,000,000	1,800,000	90	162,000

Note: 162,000 tonnes primary chromium in 1987 @ 54% average Cr is equivalent to 300,000 tonnes per year of ferrochromium.

* Preliminary year-end data subject to revision.

Source: US Bureau of the Census through AISI and USBM.

Table 2

Stainless steel import statistics

	1983 (tonnes)	1984 (tonnes)	1985 (tonnes)	1986 (tonnes)
Ingots	NAS	1,137	412	367
Blooms, slab, billets	NAS	10,142	8,936	15,544
Subtotal: semi-finished	1,316	11,279	9,348	15,911
Hot rolled sheet	4,854	6,585	5,366	3,879
Total imports	172,708	244,544	245,988	264,234
Imports as percentage of US production	10.9%	15.2%	16.1%	17.5%

Source: US Dept. of Commerce, Bureau of the Census.

NAS: Not Available Separately.

Table 3

Primary North American stainless steel producers

Company/location	Casting method	Stainless capacity (tonnes/year)*
Al Tech		
-Watervliet, NY	Billet	82,000
Allegheny Ludlum		
-Brackenridge, PA	Slab	363,000
-Lockport, NY	Ingot	36,000
Armco		
-Baltimore, MD	Billet	64,000
-Butler, PA	Slab	227,000
Atlas steel		
-Tracey, Que	Slab	90,000
-Welland, Ont	Billet	120,000
Cartech		
-Reading, PA	Billet, Ingot	118,000
Crucible		
-Syracuse, NY	Ingot	91,000
Cyclops		
-Bridgeport, CT	Ingot	91,000
Eastern Stainless		
-Baltimore, MD	Slab	91,000
Electralloy		
-Oil City, PA	Ingot	54,000
Latrobe		
-Latrobe, PA	Ingot	73,000
Jessop		
-Washington, PA	Ingot	45,000
LTV Steel		
-Canton, OH	Slab	109,000
J&L Specialty		
-Midland, PA	Slab	272,000
Slater Steel		
-Fort Wayne, IN	Ingot	45,000
Washington Steel		
-Washington, PA	Slab	141,000
		2,112,000

*Approximate

Table 4 - Grade and tonnage distribution in the 'Main Zone'

Zone	Average width m	Average grade $\%Cr_2O_3$	Specific gravity	Estimated tonnage*
Upper Main	2.59	18.2	3.37	21,807
Middle	13.80	2.74	3.0	103,500
Lower Main	0.64	23.0	3.4	5,440
Combined 'Main Zone'	17.03	6.9	-	130,747

* Tonnes/vertical/strike m over 2,500 m strike

Table 5 - Metal analyses

	Cr (%)	Fe (%)	Si (%)	C (%)	Ni (%)
Molten FeCr alloy	40.1	50.7	1.0	8.2	-
300 series transfer metal	20.6	73.7	0.8	4.5	-
400 series transfer metal	12.6	83.1	0.7	2.9	-
300 series blown metal	18.2	BAL.	0.5	0.08	8.0
400 series blown metal	11.9	BAL.	0.5	0.15	-

Table 6 - Operating costs by activity to produce stainless steel slab, expressed as a percentage

Components	Operating costs (%)
Mines, concentrator and smelting operations	30.0
Steel making operations	50.0
Labour, supplies and overheads	20.0
TOTAL	100.0